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Mainstreaming gender into water management modelling processes

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ABSTRACT

Although the Dublin principles of Integrated Water Resource Management (IWRM) are well-established, the third principle on gender is commonly missing in practice. We use gender mainstreaming to identify examples where gender-specific perspectives might influence water resource management modelling choices. We show how gender considerations could lead to different choices in all modelling phases, providing examples from three familiar components of modelling practice: (a) problem framing and conceptualisation, (b) model construction, documentation and evaluation and (c) model interpretation and decision support. We suggest a future approach for integrating gender perspectives in modelling. Including gender dimensions could strengthen modelling results by engaging with a range of stakeholders and highlighting questions, knowledge, values and choices that may otherwise be overlooked. Such an approach won't always result in a different model and results. At the very least it's a mechanism to explore and reveal gendered assumptions knowingly, or unknowingly, embedded into the model.

1. Introduction

The links between gender and water are well explored and articulated (Agarwal, 1997; Baker et al., 2015; Cap-Net and GWA, 2014; Fauconnier et al., 2018; Grant, 2017a; Mandara and Niehof, 2017; Prokopy, 2004; Ray, 2007; Vera Delgado, 2015; Zwarteveen, 2008, 2011, 1997). Institutional frameworks, such as the Dublin Principles of Integrated Water Resource Management (IWRM) and the Sustainable Development Goals (SDGs), have linked gender and water agendas in an attempt to understand the synergies between them and create informed management solutions (Grant, 2017a; Ray, 2007). As a result, it is now common for funding organisations to require gender awareness and objectives are included as a part of their project planning and implementation. However, there is a lack of guidance on what this means for modelling projects. This paper discusses this guidance gap and begins to address it by exploring the ways in which a gender perspective may affect biophysical modelling choices. We have chosen to focus on biophysical models in order to prompt a deeper appreciation of the relevance of gender considerations, even if a model is restricted to representing biophysical processes only; we assume it is obvious that gender considerations are relevant in integrated models of coupled social-biophysical systems. In doing so, we show how gender analysis could help inform modelling choices, so providing new ways for gender perspectives to be embedded in project design and implementation.

Underlying this paper is a recognition that modelling involves subjective processes. Models used in IWRM are approximate representations of chosen aspects of the water resource system. They are constructed for a range of different purposes, including interpretation (e.g. integrating different data sources to reveal system-level insights), exploration (e.g. exploring system responses to different planning scenarios), social learning with stakeholders, as well as knowledge governance (e.g. providing a transparent path from evidence base to decisions made). Modelling may be perceived as an objective, technical process, but it requires making assumptions and choices that are driven by human values (Korfmacher, 2001; Mayer et al., 2017). In this way models are social constructions. The values that underlie modelling choices differ depending on model purpose, contextual settings and the individual(s) making the choices.

Lahtinen et al. (2017) refers to these choices as modelling forks, where the modellers' values help inform the path that the model can take. The cumulative effect of these choices can lead to different results (Melsen et al., 2019). These results can then be used to create policy and make choices which affect the lives of everyone. It would be impossible to include everyone's perspectives while making modelling choices,

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however there may be value in widening the perspectives used to make these choices through understanding some of the dominant social structures in the societies the models are being built for. These social structures could be gender, age, race, ability, income etc., and in an ideal world, analysis would use theories of intersectionality to combine these structures for a richer exploration. Modellers, like everyone, have implicit and explicit biases, and so have a responsibility to ensure that their knowledge production processes include steps to recognise and address these biases.

We focus on gender for several reasons. First, there is increased demand for gender-focused outcomes from governments, donors and aid organisations, and gender equality is one of the UN Sustainable Development Goals. Second, many environmental modellers think that "gender and social equity issues should be included in their modelling research" (Escobar et al., 2017). Third, there is an opportunity to build on other work done in this space. To our knowledge there have been three other published guidelines on how to mainstream gender in environmental models. These are the Escobar et al. (2017) guidance on mainstreaming the Stockholm Environment Institute's LEAP (Long--range Energy Alternatives Planning system) and WEAP (Water Evaluation and Planning system) models, Fontana (2015) guidance integrating gender into bioeconomic modelling, and guidance notes on gender and Geographical Information Systems (GIS) by Resurrección and Johnson (2015). These guidelines do not provide details on how to integrate gender considerations in water management modeling to support IWRM. Finally, gender intersects with most other social structures and so it is an inclusive entry point for social analysis.

We have looked for situations where modelling choices may differ if informed by gender analysis. To do this, best practice water modelling guides were used as a framework for assessing common choices or forks made by modellers in water projects. We report our findings according to three modelling phases addressed in these guides: problem framing and conceptualisation; model construction, documentation and evaluation; and, model interpretation for supporting decisions. We drew on the gender-water literature to link findings with these modelling choices, so providing examples of where choices may be influenced by a gender lens.

We have not sought to quantify how modelling results would be affected by making different, gender-informed modelling choices. Given the widespread lack of guidance on how projects should include gender analysis, however, we hope that this paper can act as a starting point. Further work would include tools and approaches for more inclusive problem identification, gender-relevant data collection, and analysis tailored to report gender-specific implications. This is discussed in the 'Towards a Practical Approach' section.

It is our judgment that there are many scenarios where gender analysis may be useful for informing modelling choices, based on examples discussed in the following sections. Our work highlights the lack of guidance on what gender mainstreaming means in practice for modelling projects and demonstrates that further work needs to be conducted to ensure that modelling projects support more equitable outcomes.

2. IWRM and gender

The Dublin Statement institutionalised Integrated Water Resource Management (IWRM) in 1992 (Rahaman and Varis, 2005). The third principle reads: "Women play a central part in the provision, management and safeguarding of water … Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resource programmes, including decision making and implementation" (United Nations, 1992). Since the Dublin Principles were introduced, IWRM has become a foundational concept in water resource management. IWRM is fundamental in national water policies, and "over 80% of countries worldwide now have the IWRM principles in their water laws and two-thirds have developed a national IWRM plan" (Allouche, 2016).

Despite the well-established nature of IWRM, the third Dublin Principle is often neglected (Ray, 2007). According to a report from the International Union for the Conservation of Nature (IUCN) in 2013, "only 15% of countries had a gender policy in their water ministry, and only 35% of countries had included gender considerations in their water-related policies and programmes" (Fauconnier et al., 2018). This gap is mirrored in environmental modelling. Escobar et al. (2017) found that, despite 88% of users of Stockholm Environment Institute's WEAP (Water Evaluation and Planning system) and LEAP (Long-range Energy Alternatives Planning system) agreeing that gender and social equity issues should be included in their modelling research, only 7% were currently doing so. The Badham et al. (2019) guidelines for IWRM modelling practice argue that implementing IWRM requires guidance on how to address the integration of IWRM principles for different problems but did not explicitly deal with gender dimensions. Interviews done by the Global Water Partnership (GWP) found that water managers are "uncertain about how to engage on gender equality issues, where to engage and with whom" (Grant, 2017b). Similarly, they found that the interviewees said that "there is a lack of real strategy" on how the water sector should "tackle gender discrimination and exclusion" (Grant, 2017b). The IUCN argues that addressing gaps in integrating gender in water governance requires applying tested tools and approaches (Fauconnier et al., 2018).

3. Method and definition of terms: applying a gender lens to modelling guidelines

The guidance literature on best practice environmental modelling is substantial (Argent et al., 2016; Badham et al., 2019; Barthel et al., 2008; Beven and Alcock, 2011; Black et al., 2014; Crout et al., 2008; Hamilton et al., 2015; Jakeman et al., 2006; Lahtinen et al., 2017; Refsgaard et al., 2007, 2005; Scholten et al., 2007, 2000). Best practice guides can be found in different levels of detail, for different water management domains and for different users (Refsgaard et al., 2005). Throughout this literature, however, it is difficult to find guidance on if, or how, gender analysis should be integrated into water management models. This is the case even where modelling guidelines specifically ascribe to IWRM (Badham et al., 2019; Black et al., 2014). This paper begins to address that gap by exploring whether a gender perspective may affect choices made at the various points in the biophysical modelling process, and especially if it leads to decision forks in that process that substantially propel a modelling project down alternative paths which lead to different outcomes (Lahtinen et al., 2017).

We review gender-water relationships found in literature and assess their relevance to modelling as a preliminary foundation for developing and testing approaches useful for practitioners. We anticipate that one possible approach for integrating gender concerns into IWRM modelling would be to use gender-analysis of systems for informing subjective modelling decisions. This would aid more inclusive and diverse decision making. Modelling choices could be analysed critically and documented so that the subjective process of modelling is made more explicit and systematic (Melsen et al., 2018). Badham et al. (2019) echo this sentiment, arguing that, in best practice IWRM modelling, not all steps may be relevant but "it is valuable to consider the relevance of each step so that omission is an explicit decision and not simply an oversight." Such analysis may be challenging for modellers with no gender expertise. This paper is designed to provide some insight into how knowledge about gender relations and gender mainstreaming can relate to technical and other modelling choices. Further, it is important that interdisciplinary teams work together to support this analysis process, and for modellers to take up the challenge of becoming familiar with concepts around gender.

3.1. Terms and methods

Gender "refers to the characteristics and behaviours that different cultures attribute to the sexes." This is in contrast with sex which "refers to biological differences; chromosomes, hormonal profiles, internal and external sex organs" (Grant, 2017a). Although there are other social lenses that are just as important, gender is a good entry point for considering how alternative perspectives on water management and its modelling could change model results. The richest social analysis would use an intersectional approach to the analysis of water use, access and control. Intersectionality is both an analytical and theoretical lens used predominantly by feminist theorists to highlight how interactions between social divisions such as gender, class and ethnicity affect individuals' experiences including marginalisation (Crenshaw, 1990). This comprehensive approach is, however, beyond the scope of this paper, and the reader is referred to Braun (2011), Cole (2017), Huynh and Resurreccion (2014) and Thompson (2016) for more complete understanding of intersectional analysis of water systems. Such analyses reveal greater heterogeneity of issues across men and women, and how social differences shape access, use and control of resources like water, thereby requiring more specific and targeted policy responses to their specific needs.

In order to identify common modelling decisions or forks in water modelling projects, we identified three broad modelling phases, as described in a range of best practice water modelling guides:

a) problem framing and conceptualisation
b) model construction, documentation and evaluation
c) model interpretation for supporting decisions.

Once these phases were identified, we used a "gender mainstreaming" process to consider the relevance of gender considerations in each. Gender mainstreaming is "the process of assessing the implications for women and men of any planned action, including legislation, policies or programmes, in all areas and at all levels. It is a strategy for making women's as well as men's concerns and experiences an integral dimension of the design, implementation, monitoring and evaluation of policies and programmes in all political, economic and societal spheres so that women and men benefit equally and inequality is not perpetuated. The ultimate goal is to achieve gender equality" (United Nations, 1992). There are many definitions and interpretations of gender mainstreaming, but as applied in our paper it means we are deliberately seeking to "assess the implications for women and men" of any modelling choice. Essentially, this means that for each modelling phase we sought examples and scenarios where gender-relevant concerns would impact choices made in that phase. We acknowledge that research activities are conducted within a societal and cultural context, and that norms and values influence research designs and outcomes. It is our hope that by questioning and integrating gender into water modelling, the work of the water sector will better reflect gender concerns, and thus better inform policy makers to make gender-sensitive policies and processes.

We suggest gender mainstreaming can be applied to all modelling phases, as illustrated in Table 1, and therefore should be considered from the outset of a modelling exercise. We have structured the results of our review according to these modelling phases in the sections below. This paper does not attempt to explore all points in Table 1, focusing only on specific examples that are relevant to each phase. The call to integrate gender into modelling is sometimes interpreted as a request for modelling platforms that can include explicit representation of men and women's behaviour and decisions in modelling. Agent-based models, system dynamics models and Bayesian networks are examples of integrated modelling platforms that accommodate these details (see Kelly (Letcher) et al., 2013). We limit our focus to biophysical modelling in this paper for several reasons. First, gender considerations are often assumed to be beyond scope in a biophysical modeling exercise and we wanted to test that assumption. Second, it is more obvious that gender considerations are relevant when modelling social and economic aspects of a system, and there is more guidance available on how to do it; we are interested in identifying what gender mainstreaming processes may be useful for biophysical modellers in order to address the lack of guidance in this area. The core ideas and some of the examples used in this paper have been drawn from Packett et al. (2018), which is a more wide-ranging review that is not limited to biophysical models.

Table 1
Suggestions of where gender mainstreaming can be applied in different modelling phases. Based on Packett et al. (2018).

Problem framing	Model construction	Model interpretation
•Deliberately include gender considerations when determining modelling objectives and scope •Use gender analysis to reveal contextual social relations and facilitate diverse stakeholder engagement to include multiple perspectives, including gender •Include gender social goals as criteria for success and design relevant reporting metrics	•Consciously deliberate on the values that inform modelling choices such as model structure and scope, timescales, scenario specification and handling of uncertainty. •Identify potential for gender-informed and disaggregated data to reveal insights and options that are masked by aggregated data •Account for missing gender-specific knowledge by assessing implications for confidence in modelling results and associated risks •Define calibration metrics and model evaluation procedures so model performance is evaluated according to model utility and relevance in addressing gender-informed objectives	•Be transparent about who decides how a model is used (e.g. who chooses optimisation criteria, who evaluates modelled management options) and why •Explore consequences of gender-related uncertainties using appropriate uncertainty, risk or vulnerability analysis methods •Document and communicate how gender analysis has or has not informed modelling decisions and why.

4. Insights gained from applying gender mainstreaming to modelling decisions

4.1. Problem framing and conceptualisation

Problem framing and conceptualisation involves articulating the problem and specific questions to be addressed through the modelling exercise. It is where judgments are made about what is in or out of scope for addressing the problem, creating the potential for excluding considerations that are considered important by some but not by others. There are strong arguments for integrating gender considerations right from the beginning of projects. Interviews with water professionals done by GWP found that one disincentive to including gender considerations is that "gender issues are 'tacked on' rather than considered upfront which makes them hard to integrate and act upon properly" (Grant, 2017b). Merritt et al. (2017) found that one of four factors of success deemed 'always essential' by technical experts in Australian water resource projects was "sufficient critical thought given to the problem framing and the role of modelling early in the project." This is because questions at this stage create a path dependency that can determine the course of a modelling project (Lahtinen et al., 2017). We explore the possibility that including gender as an analysis lens when framing the problem could alter how a model is constructed, potentially leading to different insights and model-informed decisions.

Individuals have different preferences and values that inform how problems are framed and expressed in models (Lahtinen et al., 2017;

Mayer et al., 2017). "Values" are beliefs that refer to personal goals, they typically transcend specific actions and situations, and they guide people's sense of right or wrong (Schwartz, 2012). In investigating the values that drove their modelling choices, Mayer et al. (2017) studied 11 scientists in the same climate modelling team and revealed that while some values were common across the scientists (such as "consistency" in evaluating modelling results) there was also considerable diversity (only two mentioned "basic rights protection" as one of their modelling ethical values). This is important because explicit and unconscious preferences can alter modelling choices and results (Lahtinen et al., 2017; Melsen et al., 2019).

A diverse set of perspectives is one way to reveal the different values prevalent within the decision making and stakeholder context and how these could change problem framing and subsequent modelling decisions. Mayer et al. (2017) suggest that active efforts to make implicit values known facilitates better scrutiny within the team and external reviewers. Even within research groups, members of a modelling team rarely have the same level of power and influence to exert their preferences on decisions. Reflecting on power imbalances will be fruitful and we refer readers to work on team decisions and participation, intersectionality and institutional culture (Cech and Pham, 2017; Cornwall, 2008; Grant, 2017b; Holleran et al., 2011; Torino et al., 2018; Walby et al., 2012; Wu and Jing, 2011). The subjective choices in projects create multiple decision pathways. Along the way, value or ethical judgments are made, yet only the final product is visible at completion when informing decisions. Science produces information products that are often used elsewhere. We contend that good practice behooves scientists to analyse and document these ethical choices so that they are replicable and can be used to inform how any final product is interpreted and used.

Question framing can reveal or obscure certain issues, so affecting the type and quality of data collected. A study undertaken by the Social Observatory found that when village members designed their own questions to investigate their livelihoods, there was only a 17% crossover in questions developed by the Indian National Sample Survey which targeted the same issues (Rao, 2017). Questions to target gender equality could be framed as: "How much do you spend on the purchase of vegetables in a month?" (World Bank) or "Does the person who eats last get enough to eat?" (Women from Bihar, India) (Rao, 2017). Different values across researchers and stakeholders can inform the types of questions asked and associated data needs. For example, Baker et al. (2015) characterised gendered difference, as well as differences between researchers and community members, in mapping landscape features in a sub-catchment in Ethiopia. When creating input layers for their Soil and Water Assessment Tool (SWAT) model, researchers focused on land use and crop type to classify the landscape. Women tended to classify areas in terms of soil type, which were proxies for productivity and land degradation, and at a finer resolution than maps developed by the Food and Agriculture Organization (FAO). Men, on the other hand, classified larger areas of land as grazing, reflecting their role in stewarding livestock. This means that in their maps, land that would have been assigned crop or soil type was seen as grazing. This study showed how differing perspectives can influence judgments of what data is relevant for understanding and addressing a problem. Similarly, the value system of the researcher can influence final outcomes, especially given it is often the researcher who selects the input data.

To be gender sensitive, water modelling projects can include a range of perspectives through diverse framing of questions so that model conceptualisations are informed by that diversity and deliver insights that are robust to this range. This could be done in a mix of ways. Tools and methods for eliciting knowledge directly from stakeholders have been reviewed by Voinov and Bousquet (2010) and Voinov et al. (2016), drawing on the literature in participatory modelling methods. Seeking specialist gender expertise is also valuable for bringing relevant theories and practices to problem framing and conceptualisation. Such efforts may pose problems and raise questions that cannot be addressed by biophysical models alone, and if this is the case then it will be important to ensure the conceptualisation of any biophysical modelling is such that it can connect with and contribute meaningfully to the broader problem framing.

4.2. Model construction, documentation and evaluation

We refer to 'model construction' in broad terms, referring to decisions about modelling approach and design (informed by problem conceptualisation), building a working model and implementing it. These steps are generally considered to be specialist modelling decisions separate from social analysis, however even technical modelling choices can reflect values-based assumptions. In the next sections we give examples of how both the modelling approach and its implementation are affected by stakeholder and researcher values that are relevant to gender.

4.2.1. Choice of modelling approach

Several decisions are made when choosing elements of the modelling approach. There are decisions about the nature of the model itself (e.g. qualitative or quantitative, analytical or numerical, process-based or observation-driven, deterministic or stochastic, or a hybrid mix), and there are also decisions about who is involved in model design, building and testing: will it involve specialist modellers only or does it include participatory co-production with stakeholders? Kelly (Letcher) et al. (2013) describe a range of factors that affect choice of modelling approach: model purpose, data availability, system conceptualisation, treatment of uncertainty, and appropriate mode of output generation (e.g. scenario-based, analytical solution or optimisation). We suggest there are gender-relevant considerations in each of these.

For example, the treatment of uncertainty is shaped by attitudes towards risk. Gender differences in risk and ambiguity preferences have been found regularly in laboratory and field behavioural studies, although there are some exceptions (Croson and Gneezy, 2009). A study investigating flood risk attitudes in a large sample in Serbia found that men perceived themselves to be more prepared for flooding events than women, while women indicated high concerns about flood risks (Cvetković et al., 2018). Risk-averse values could influence the type of modelling preferred and/or the specification of modelling objectives. Risk reduction decisions could be better informed by modelling approaches explicitly characterise statistical distributions and probabilities. Alternatively, plausible scenarios spanning extreme or undesirable outcomes could be modelled in cases where probabilistic approaches are not possible, as can be the case for complex, integrated water models. We note also that risk awareness and attitudes change over time, and so modellers may need to be responsive to changing appetite for more specific insights into risks. These examples show that social preferences of individuals and groups can be reflected in the choice of modelling approach so that model is suitable for generating outputs that are directly relevant to stakeholder priorities. In this way, the choice of modelling approach can be assessed according to how well it represents the interests of diverse stakeholders.

It is common for modellers to come to a new problem having already chosen their modelling approach. This reality presents practical challenges in bringing a genuinely open mind to questions of model choice and implementation. Even if a modeller has some flexibility in their choice of modelling approach, their choices will be limited by their own experience and capability, as well other factors that determine the accessibility of different modelling approaches, including time, funding and available modelling infrastructure. At a minimum, we recommend making a deliberate effort to consider a broader range of modelling approaches, review their strengths and weaknesses in addressing the problem as framed, and spell out explicitly the criteria being used to choose one modelling approach over another. By ensuring that gender-relevant criteria are part of this assessment it should be possible to document the model's fitness for purpose and outline supplementary

measures that can be taken to account for anticipated shortcomings in the modelling approach.

4.2.2. Choices in model implementation

Once a modelling approach is chosen, assumptions made when implementing the model are vital context for interpreting results and evaluating fitness for purpose. Melsen et al. (2019) studied the effect of subjective modelling decisions on the results of flood and drought event simulations in the Swiss Thur basin. They focused on four modelling decisions; the spatial resolution, the spatial representation of the forcing, the calibration period, and the performance metric of the model. They found that these choices affected the modelling results significantly. This demonstrates that, "embedded in the model are assumptions on what is important, and what is not … [and] decisions on (temporal and spatial) scale, numerical methods, dealing with data scarcity and uncertainties are not neutral. They influence not only the model results, but also what the model can do, who can use the model, and for what purposes" (Melsen et al., 2018).

Hydrological models are often calibrated by optimising an objective function, and it is well-recognised that different objective functions are appropriate for different modelling purposes (e.g. see Vaze et al. (2011) for guidance on choice of objective function). For eco-hydrological applications, for example, it is important to ensure the model adequately characterises specific attributes of the flow regime (e.g. low flows or cease to flow events) (Bunn and Arthington, 2002). Similarly, the type or timing of flow that is most important may be different for different people. In the Chhattis Mauja irrigation system in Nepal, Zwarteveen (1997) found that even though men and women were working cooperatively as co-farmers, they tended to have different priorities about water flow conditions. Their work made them aware of the timing of delivery of water. Men tended to care about water arriving at the start of the irrigation season because they were responsible for land preparation. Women agreed, but also stressed the importance of ongoing access to water throughout the irrigation season, because reduced rice paddy pond depth encourages weed growth and they are responsible for weed management. In modelling this system, there are different gendered perspectives on which flow attributes are most important for farming. This example illustrates that gender may affect datasets, methods chosen for model calibration and evaluation, as well as which metrics to report.

Gender is not the only social lens that could inform modelling choices, and sometimes it won't be the most important. For example, choosing temporal scales is an important step in a modelling process. Hydrological models used for multi-decadal projections are likely to be less complex and include fewer processes for computational efficiency. Consequently, model results will be appropriate for assessing long-term impacts but may not provide the level of detail needed for current, day-to-day operations or management (Mayer et al., 2017). Choices such as model complexity and time step involve value judgments. Reporting time scales of model output will need to reflect those most relevant to stakeholders. In a large-scale statistical analysis across 53 countries of time preferences such as discounting and uncertainty avoidance, Wang et al. (2016) found that gender was not a significant predictor of time preferences, however different cultural practices tended to change time preferences. Other work has shown that participants' ages can impact time preferences (Green et al., 1994). This implies that perceptions of time might impact the preference for information produced by modelling to aid water management decisions.

There are practical challenges in applying gender mainstreaming to the day-to-day details of building, calibrating and testing a model. To do so most effectively requires involving stakeholders at all stages in model development, which entails iterative processes that are time and resource intensive. The available methods, and recommendations for navigating associated challenges, are reviewed in the participatory modelling literature (e.g. Etienne, 2012; Voinov et al., 2016; Voinov and Bousquet, 2010).

4.3. Model interpretation for supporting decisions

Choices in how to interpret and communicate results are critical in shaping how modelling supports the decision-making process. The following sections use examples relating to multi-criteria optimisation, aggregate indicators and handling of uncertainty to give options for including gender considerations when interpreting and using model results.

4.3.1. Performance and optimisation criteria are explicit value statements

If a hydrological or integrated water resource model is used within a decision support context which includes weighting or optimising across different criteria, or making management recommendations, then this process involves a series of implicit value judgements. Choice of optimisation method (and objectives), the criteria against which success is measured, and the relative weightings across different criteria, all have an impact on how the model is interpreted, and so influence management decisions. It is useful to reflect on who is involved in these decisions, whose voices are excluded, and how inclusion/exclusion supports or impedes model legitimacy. This raises questions of power in decision-making.

In developing fisheries rights, Joubert et al. (2008) undertook a study which revealed that the proposed criteria for their Multiple Criteria Decision Analysis process were different between the fisheries agency staff and relevant community stakeholders in South Africa, and that these groups valued various criteria differently. This suggests that the criteria for weighing options in resource management and their relative importance can change depending on who has access to (or control of) the decision-making process. This is pertinent for the water sector because sometimes the right to participate in these water management conversations can be a privilege afforded largely to men. For example, in South Asia, government irrigation agencies remain male dominated with women constituting only 2–4% of the engineering staff (Zwarteveen, 2011). This is often true of community-level water users organisations too (Agarwal, 1997; Meinzen-Dick and Zwarteveen, 1998; Ray, 2007; Samee et al., 2015; Zwarteveen, 1997). However, it is government staff that often have control of information production and dissemination, thus giving them power to shift 'values, beliefs and norms' (Srinivasan et al., 2017).

4.3.2. Aggregate indicators mask implicit value judgments and distributional consequences

Aggregate indicators can fail to convey severe impacts for some people and conceal whether or not effects are distributed equitably (Adams, 2000; Amoretti and Vassallo, 2016). A review by the World Commission on Dams (WCD) judged that aggregate costs and benefits of large scale dam projects are not comprehensive enough for approving infrastructure programmes because distributional effects are masked and equitability cannot be assessed (Adams, 2000). Reporting of distributional effects are important for ensuring that more marginalised and vulnerable minorities benefit from projects and do not bear disproportionate unwanted impacts. They emphasise that excluding gender from social impact analysis is particularly misleading and risky because "hard numbers (however crudely generated) command attention from planners. Once created, such numbers become divorced from warnings about their reliability, and are used in decision-making by donor and government decision-makers. If such numbers are wrong, or omit vital areas, they can be dangerously misleading … Things that can be quantified tend to dominate decisions at the expense of things that cannot be quantified" (Adams, 2000). This can be particularly true for indicators that focus on economic analysis.

For example, the US$8 billion transnational Lesotho Highlands Water Project (LHWP) is a programme that constructed five dams and cross-national tunnels in Lesotho in order to generate national income from selling water to South Africa (Braun, 2011). Feasibility and initial objectives suggested that Lesotho would benefit from the project by

broadening the economic base and development of remote mountain regions (Yu, 2008). In practice, despite economic growth, poverty did not improve, economic inequality remained high and Lesotho experienced social and environmental costs (Yu, 2008). The filling of the dams led to a serious decline in resources for affected households, with the burden falling disproportionately on women (Braun, 2011; Mwangi, 2007). The project increased the reliance of households on wages and formal markets. Due to the patriarchal system in Lesotho this reliance increased gender inequalities by giving men greater control over household resources (Braun, 2011). Such diverse impacts are difficult to anticipate and make visible in aggregate estimates of economic costs and benefits. Effects such as these prompted the WCD to call for gender-sensitive social analysis of dam projects.

Aggregation is often necessary in practice, but when doing so it is useful to pay attention to what is excluded in aggregation, retain and report distributional properties where possible, and provide supplementary interpretation to compensate for omissions resulting from aggregation.

4.3.3. Uncertainty and gender considerations

Gender Impact Assessments (GIAs) can help to reveal access and control of water based resources and potential impacts of projects (Simon, 2013), however gender analysis is often limited by lack of data (Adams, 2000; Escobar et al., 2017; Ray, 2007). Even with more resources dedicated to the collection of data and assessment of potential gender impacts, the ability to anticipate and usefully characterise impacts in complex social systems is limited. Even if it is not possible to resolve issues of data scarcity and poor predictability, better acknowledging these realities is an important first step towards including them in impact analyses and assessment. In particular, it opens options for including these unknowns in more suitably encompassing uncertainty analyses.

Smithson (1989) offered a 'taxonomy of unknowns' in which an important distinction is made between ignorance that is treated as 'irrelevant' (i.e. ignored from the analysis) versus ignorance that is recognised as 'errors'. Errors can be explored, characterised and included in the analysis and interpretation, even if these errors cannot be reduced. For example, if data are reported at household level only and there is no gender disaggregated data, it is still possible to test the sensitivity of the analysis to plausible data ranges that are representative of these unknowns. A subsequent step is to assess whether any sensitivities could have a bearing on final decisions informed by the analysis. There are more options for handling uncertainty than simply trying to reduce it and there is a growing range of methods for water management planning under "deep uncertainty". Herman et al. (2014) used a multi-stakeholder multi-objective robust decision-making framework to better understand "robustness tradeoffs" between different water supply options in the face of deep uncertainties related to climate change, financial risks and population pressures. Uncertainty, risk and/or vulnerability analysis can help us acknowledge our ignorance and explore its possible consequences.

5. Discussion

5.1. Towards a practical approach

We have used examples to show that including gender perspectives stands to make a material difference to choices made in problem framing, model conceptualisation, modelling approach, implementation and interpretation. These examples demonstrate the potential for a modelling approach that seeks to incorporate gender perspectives. Integrating gender analysis and including a range of diverse perspectives in model development decisions could be one approach for modelling projects to engage with gender-relevant objectives. Choices could be assessed and documented for the major modelling phases to state explicitly who was involved and what values or criteria informed subjective decisions, particularly where this may have led to significant decision forks. This would be equivalent to 'gender mainstreaming' the modelling process.

Applying this approach to a project would involve contextual gender analysis to provide the input data for assessing decisions made during model development and use. Gender analysis can be aided through a range of toolkits such as the Harvard Analytical toolkit, Global Water Partnership's 'Gender equality and inclusion in water resources management' action piece or World Water Assessment Programme's Toolkit on Sex-Disaggregated Water Data (Fletcher and Schonewille, 2015; Grant, 2017c; South-East Asia and the Pacific Multidisciplinary Advisory Team, 1998). We are not aware of this approach being used systematically in any water modelling projects. There is an opportunity to apply and test this method to explore how much of an impact conducting this process would make.

As mentioned earlier, an intersectional approach (i.e. one that takes account of stakeholders' social identities such as culture, class, gender) would yield richer data and ways in which decisions and values are prioritised. Time and resource limitations are common barriers to an intersectional approach, with its requirements for multidimensional analyses of the social confluences of gender, class, ethnicity and race. Gender intersects with most other social structures and so it is an inclusive entry point for social analysis. A gender-sensitive contextual analysis (i.e. literature review, stakeholder consultation with key community leaders and civil society organisations) can reveal key intersectionalities to be prioritised in further intersectional analysis. Further analysis could include using Naila Kabeer's Social Relations Framework (Kabeer and Subrahmanian, 1996) to provide an institutional analysis of how inequalities are produced within and across the different scales of family/kinship, communities, market and the state. In the context of water resource management, this might mean exploring how women and marginalised groups are denied water access and consumption at the household or community level, to how market pricing of water limits the poor from accessing drinking water, to how state policies around water overlook the contribution of women's role in water resource management.

We recognise that applying gender mainstreaming won't always make a difference to modelling choices. Rather, if gender outcomes are a specified goal of a project, modified modelling practice could ensure that if gender is judged to be unrelated to a modelling decision, this view is an informed, conscious choice supported by documentation. In this way, a gender mainstreaming approach might provide a simple, transparent structure for assessing and reporting on modelling decisions in a gender-relevant way. This process may be used to substantiate claims that modelling results are robust to differences in gendered dynamics. For example, in the SWAT and gender case study by Baker et al. (2015) cited earlier, despite the differences in conceptualising the landscape between researchers, and between male and female stakeholders, the final modelling from all these perspectives yielded similar results. This is because during their mapping exercise, the three groups assigned similar areas to agriculture which was the parameter that the rainfall-runoff and curve number was most sensitive to. Through documenting this process the team now has evidence that their results are gender informed and thus valid (Diekmann and Zwart, 2014). Additionally, where gender may not overtly be part of the goals and outcomes of a modelling project, including gender and social dimensions has the potential to strengthen modelling results by engaging with a wider range of stakeholders and highlighting possible questions, knowledge, values and choices that may otherwise be overlooked. It may also lead to informed insights in future modelling and IWRM studies conducted elsewhere.

This reflects the Diekmann and Zwart (2014) argument that "fairness" can be used as a test for quality in similar ways to other validation and verification tests. They "conceptualise fairness as the maxim of giving due and equal attention to the interests of all stakeholders independent of their social power or status". They argue that using fairness as a test of whether a model is "fit for purpose" will guarantee that "a

model provides what is practically required and theoretically desirable: mutual confidence in construction, usage and choice of embedded and implied values among all stakeholders." We contend this is a relevant test for IWRM modelling efforts, and hope to have made a contribution towards this aim.

5.2. Relevance of gender in modelling decisions

Our aim has been to ask whether modelling could unfold differently if gender (or other equity perspectives and intersectional considerations) were to be mainstreamed into each stage of the modelling process, and would these differences matter? Our exploration has been a conjectural one. At this point we have not applied the approach suggested in the previous section to a specific model or case study. The approach will need to be tested rigorously and evaluated against suitable criteria.

In addition to the motivations for gender integration laid out earlier, the potential approach is also relevant to projects funded by institutions with gender goals. Consider, for example, the Australian Government Department of Foreign Affairs and Trade (DFAT), where improved outcomes for women and girls are a high priority against which projects and their activities are evaluated. For these DFAT-funded projects that include hydrological modelling, there is little guidance on how to link gender to the detailed mechanics of hydrological modelling. It is not immediately clear that taking a gender perspective would see any change made to the development of a rainfall-runoff model for a catchment, a technical task for which there are well-established model development steps. A modeller might reasonably ask, for example: "I work on developing rainfall surfaces as inputs to hydrological models - why do I need to think about gender?" As demonstrated by examples described in this paper, metrics used by modellers for selecting model inputs or calibrating models against observations could have real-world, gender-specific relevance. The development of rainfall surfaces requires judgments about what attributes of the rainfall are most important to represent: if the intended beneficiaries of the modelling are women located on a floodplain, is it more appropriate to use rainfall inputs that are consistent with total annual rainfall, or is it more relevant to use inputs that capture the timing and magnitude of extremes? Our intention is to prompt questions of this type and increase awareness of where a gender lens may reveal different answers.

By suggesting that modelling teams better recognise the subjective nature of their modelling choices and subsequent decision forks, it provides a natural entry point for bringing others' perspectives into the modelling process earlier. Our work provides another argument for the benefits of participatory practices that foster genuine engagement with stakeholders and their priorities, even if the model represents only biophysical, and not social, processes. Furthermore, documentation of such practices provides transparency and a useful form of accountability to stakeholders and funders, and for modelling teams to monitor and learn from their experience according to their own quality assurance requirements.

Some may interpret our recommendations to mean "involve both men and women in any modelling exercise". The process of gender mainstreaming is not that simplistic. It is about asking whose interests and perspectives are represented and whose are excluded, and recognising that modellers of any gender will not necessarily have that insight and awareness when going about their model development. A team of all-female modellers would not necessarily have any more informed insights into women's perspectives in a water system in a different country with a very different culture to their own. Similarly, an all-male modelling team could well make good progress working with a gender specialist (who could be any gender) who facilitates participatory processes for eliciting gender-relevant insights across a diverse range of stakeholders.

We have explored these ideas with biophysical modellers working in Australian and international contexts, and in many of these conversations initial doubts about the relevance of gender have been shifted. But it has taken curiosity, open-mindedness and the discovery of tangible, plausible examples in the course of these discussions to enable such shifts. The modelling guidelines (such as Black et al., 2014) have been a useful entry point to those discussions, and allowed us to discover relevant examples that resonate with modellers. By providing tangible examples in this review we hope to prompt similar discussions in other modelling groups and enable further explorations of the practical value of applying gender mainstreaming in model development practices.

6. Conclusions

Ensuring that water management decisions lead to equitable outcomes is increasingly a priority of water management decision makers. Given the complex task of water management, models and/or modelling frameworks are often used as a tool to support decision making. Thus, it is useful for modellers and model users to have methods to assess and report how questions of equity and inclusivity have informed their modelling choices and practices. Although this is inherently difficult to do, systematically evaluating modelling choices, especially those that may create substantial modelling forks, from different perspectives can prompt creative thinking about alternatives. Decisions from the beginning to the end of projects are influenced by values. Given this, making a more deliberate attempt to identify and then include others' perspectives (including across gender) can reveal situations where different conceptual framing, data choices, objective functions or priorities might impact a model's development and outcomes.

This paper provides examples within three key IWRM best practice themes where gender considerations might impact a modelling choice: problem framing and conceptualisation; model construction, documentation and evaluation; and model interpretation for supporting decisions. Areas of model development that could be affected include the initial choice of modelling approach, parameterisation and calibration. Furthermore, the interpretation, handling of uncertainty and choice of aggregated reporting indicators can all be reviewed in light of gender-specific objectives. At the very least, gender mainstreaming provides a process for exploring, and then making explicit, the range of gendered assumptions knowingly, or unknowingly, embedded into the model. All modelling projects are likely to have resource constraints and it can be difficult to assess what analysis needs to be integrated and what can be excluded. Gender analysis will be important for teams that have equitable water management as a goal, and where gender analysis is excluded this should be acknowledged as a project limitation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further Reading

In this paper we have drawn on gender studies literature ranging from gender theories and frameworks, to practice-led case studies which informed our work in mainstreaming gender into water modelling. We have also provided an example reading list below for those interested in exploring the literature.

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